7.—Analyses of Western Australian iron meteorites

by
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Manuscript received 18 July 1972; accepted 22 August 1972.

Abstract

All available analytical data on iron meteorites found in Western Australia are presented. The contents of nickel, cobalt, gallium and germanium in 33 of these meteorites was determined using X-ray fluorescence spectrometry, thus enabling these meteorites to be classified structurally and chemically. The new analytical data enabled a number of paired falls to be distinguished.

Introduction

The first recorded discovery of meteorites in Western Australia occurred in 1884 in the sub-district of Youndegin, some 110 km east of the town of York. Four pieces were recovered, and a description and chemical analysis of the largest of these specimens was given by Fletcher (1887). The analysis revealed a new type of graphitic carbon which was named cliftonite by Fletcher, who realised that its presence could be a significant clue to the origin and formation of meteorites.

In fact meteorites contain far more information about the early solar system than was once believed (Anders 1971), and analytical data which have accumulated in the past two decades have played no small part in our present understanding of the formation, evolution and chronology of the solar system. The monumental work of Suess and Urey (1956) on the abundances of the elements, depended largely on meteorite abundance data. This work enabled theories of element formation to be formulated, and the work of Burbidge *et al.* (1957) for example, depended to a large extent on the abundance table of Suess and Urey. Meteorite abundance data has continually been refined over the past decade and the recent abundance table of Cameron (1968) draws heavily on this information. It is probably true to say that our present understanding of nucleosynthetic processes in stars would not have been attained if accurate analyses of meteoritic material had not been available.

It is significant that all the early meteorite discoveries in Australia were siderites (irons). The first Catalogue of Western Australian meteorites (McCall and Delaeter 1965) lists 29 irons, 4 stony irons and 15 stones. There were almost twice as many irons as stones, despite the fact that on a world-wide basis the situation is almost the reverse (Mason 1962). This is undoubtedly due to the fact that irons are much more easily recognised than are stony meteorites, and in Australia with its deserts and large areas of arid land, irons are preserved for a much greater length of time than stony meteorites. Again it is probably significant that the Australian aborigine was not cognisant of the use of metals, and therefore had little interest in iron meteorites which may have been discovered.

Since the publication of the Catalogue in 1965 a number of new meteorites have been reported, and many of these have now been incorporated in the Collection. This has necessitated the publication of a Supplement to the Catalogue (McCall 1968) and a second Supplement is now in preparation.

Many meteorites found in Western Australia have been extensively studied both in Australia and overseas. This interest is partly due to the pioneering work carried out by the late Government Mineralogist, Dr. E. S. Simpson who published a number of papers describing local meteorites over a period of nearly 40 years. Simpson always took great care to analyse the iron meteorites for the major elements—iron, cobalt and nickel, and for the minor elements copper, phosphorus, sulphur and carbon. Many of his results are extremely accurate and have been summarised in this work.

Analytical method

In this paper an attempt has been made to tabulate all the analyses that have been carried out on Western Australian iron meteorites. It is true that some of the earlier data can no longer be regarded as reliable, but it was felt that a complete record should be made at this time. On the other hand, where a number of analyses have been made by various authors, a recommended value has been given.

The evaluation of analytical data for iron meteorites is by no means a simple task, and, as Moore *et al.* (1969) has pointed out, is sometimes more difficult than for stony meteorites, despite the simpler composition of siderites. In general analysts avoid using samples which include large troilite or schreibersite inclusions. Thus most analyses are not representative of the meteorites as a whole, but only of the metallic phase. For example the sulphur values usually refer to the metallic phase, but this is by no means obvious from many of the original publications. Certainly the sulphur content of the meteorite itself will be significantly different if troilite occurs to any extent. Again iron meteorites are inhomogeneous, and unless adequate sized samples are analysed, there can be no guarantee that the results are typical for the meteorite as a whole.

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A more serious problem is that of evaluating accuracy and precision, particularly when different analysts and analytical techniques are involved. Work on the silicate rock standards G-1 and W-1 has shown that there is an alarmingly wide spread in the results obtained by different analysts, or even by the same analyst at different times. (Fairbairn *et al.* 1951). Lest it be imagined that with the advent of modern methods of analysis such disparities no longer exist, it is instructive to examine the paper of Fleischer (1969) where new analytical data on these standard rocks is summarised.

There is no reason to believe that the situation is any better for iron meteorites than for silicate rocks. In fact the present study reveals large scale discrepancies between analyses carried out on the same meteorite. Cobalt, for example, has invariably been overestimated in the old analyses.

The elements in iron meteorites may be divided into four groups. Firstly, the major constituents of the metallic phases—iron, nickel and cobalt. These three elements usually account for over 99% of the total composition of iron meteorites. Secondly the important trace elements gallium, germanium and iridium on which a chemical classification has recently been devised. Thirdly, the elements found dissolved in the metallic phases and in non-metallic mineral inclusions—carbon, phosphorus, chromium, sulphur and nitrogen. Finally the trace elements such as copper, zinc and the noble metals. In point of fact almost every non-gaseous element occurs in iron meteorites, but unfortunately very few analyses have been made on these trace elements in the Western Australian iron meteorites.

In addition to summarising the analytical data which could be located in the literature, each meteorite was analysed for nickel, cobalt, gallium and germanium as part of the present project. Nickel and cobalt, are major constituents of any iron meteorite, and traditionally have always been regarded as essential analytical data. In point of fact cobalt is not particularly useful in classifying siderites, since its abundance range is very limted. The nickel content of an iron meteorite has long been recognised as one of the essential criteria used in classifying siderites, and it still serves an important role in any structural or chemical classification.

The importance of determining the content of gallium and germanium has been recognised only in recent years. The significance of these elements stems from two main factors. Firstly, gallium concentrations in iron meteorites can vary by a factor of 400, and germanium concentrations by a factor of 14,000. These ranges may be contrasted with cobalt, where the concentrations do not vary by more than a factor of 2, and for nickel where it is unusual for the range in concentration to be greater than 4. Secondly, gallium and germanium concentrations in iron meteorites are highly correlated to each other and to nickel, and in addition are quantised into a number of distinct groups. After early work by Goldberg *et al.* (1951) and Lovering *et al.* (1957), J. T. Wasson and his associates determined the abundances of gallium, germanium, nickel and iridium in several hundred meteorites in order to elucidate the classification of iron meteorites, (Wasson 1967b, Wasson and Kimberlin 1967, Wasson 1969, Wasson 1970, Wasson and Schaudy 1971).

On the basis of their analytical data, which were determined mainly by neutron activation analysis, eleven resolved chemical groups have been defined. It is believed that the groups may represent different meteorite parent bodies or perhaps regions within a parent body characterised by different chemical or thermal environments (Anders 1964). This chemical classification has been used in the present work.

A Siemen's S.R.S.-1 X-ray fluorescence spectrometer equipped with a molybdenum tube, lithium fluoride crystals and a scintillation detector was used for the analyses. A flat surface on each of the meteorites was polished with successive grades of carborundum paper until a smooth, highly polished surface at least 1.25 cm in diameter was prepared. This surface was exposed to the primary X-ray beam, and peak and background readings were taken for each of the four elements. The spectrometer was calibrated for each element by standard alloys and from a number of siderites with well-established composition. Details of the technique will be presented elsewhere (Thomas and DeLaeter 1972).

The nickel, cobalt, gallium and germanium values measured in the project, must be qualified by error limits of ± 0.02%, ± 0.05%, ± 10 ppm and ± 10 ppm respectively. These errors represent the 95% confidence limits based on counting statistics of the experiment and the calibration of the instrument. They make no allowance for the heterogeneity of the sample. X-ray fluorescence spectrometry possesses the advantage of being non-destructive, but it suffers from the serious disadvantage of sampling only a very small volume of the specimen. The infinite thickness of an iron meteorite to the X-radiation used in this experiment was only of the order of a few thousandths of a cm, whilst the area of the incident X-ray beam was approximately 1.2 sq cm.

In an effort to overcome this deficiency, each sample was analysed in at least two positions, but this did not alter the fact that the statistical errors stated above are probably less than the possible inhomogeneity errors imposed by the technique itself. The latter errors are certainly worse for the coarse octahedrites than the fine-grained siderites.

Results

Table 1 lists the classification, specific gravity, cooling rate and contents of the elements nickel, cobalt, gallium, germanium and iridium for the 37 iron meteorites which have been found in Western Australia. Multiple entries have been made for Mount Edith I and II, Premier Downs I and II and the Youndegin meteorites. There

TABLE 1

Classification and major element analyses of iron meteorites

Name	*Classification Structure	Chemistry	Specific gravity	Cooling rate °C/10⁶yr.	Ni %	Co %	Ga ppm	Ge ppm	Ir ppm	†References
Avoca (Western Australia)	Om	IIIA	7·8		8·86	0·52		48		This work
							21·9			1
					8·65	0·52				2
					8·76	0·52				Recommended value
Balfour Downs	Om-Og	I	7·8		8·15	0·50	58·4	194		This work
				1·5						3
					8·39		56·4	194	2·0	4
					8·39	0·52				5
							62·1			1
					8·31	0·51	59	194		Recommended value
Ballinoo	Opl	IIC	7·8		9·84	0·54	41	103		This work
				~20						6
					10·06	0·54	44	91		7
					9·72		39·0	94·4	9·0	8
					9·8					9
					8·85	0·74				10
					9·87	0·60				11
							33	100		12
					9·86	0·55	39	95		Recommended value
Dalgaranga			6·8		8·40	0·45	40	59		This work
					8·63					13
					8·45					Recommended value
Duketon	Om	IIIA	7·8		7·61	0·49		40		This work
							21·2			1
					7·25	0·49				14
Gosnells	Anom.	I-An3	7·6		6·04	0·45	49	252		This work
Gundaring	Om	IIIA	7·7		8·18	0·50	10	50		This work
				4						6
					8·18	0·5				13
					8·32	0·61	19	38		7
					8·22	0·53	16	43		Recommended value
Haig	Om-Og	IIIA	7·8		6·93	0·49		32		This work
					7·36					11
							16·2			1
					7·0					Recommended value
Kumerina	Opl	IIC	7·8		9·61	0·54	37	95		This work
				~100						3
					9·55					13
					9·69		36·8	93·4	8·1	8
							39·3			1
					9·64		37	94		Recommended value
Landor	Of									13
Loongana Station (iron)	Om	Anom.	6·9		7·78	0·47	62	179		This work
					7·4					11
					7·7					Recommended value
Milly Milly	Om	IIIA	7·8		7·56	0·49		35		This work
				3·5	7·45					3
					7·84	0·77				13
							19·9			1
					7·56	0·50				Recommended value
Mooranoppin	Og-Ogg	I	7·3		6·87	0·45	84	346		This work
				~3·5						6
					6·91	0·50	79	396		7
					7·21	0·88				15
					6·90	0·48	81	370		Recommended value
Mount Dooling	Anom.	I-An3	7·7		6·05	0·45	60	233		This work
					6·41	0·48	61	193		7
					6·26		51·5	234	1·2	4
					5·96	0·64				15
							57·8			1
					6·20	0·47	57	225		Recommended value
Mount Edith I	Om	IIIB	7·5							This work
				2						6
					9·40	0·55	15	33		7
					9·45	0·75				15
					9·6		20·1	38·4		16
							20·5	34		12
					9·45	0·625				11
					9·48	0·55				Recommended value

Name	*Classification: Structure	*Classification: Chemistry	Specific gravity	Cooling rate °C/10⁶yr.	Ni %	Co %	Ga ppm	Ge ppm	Ir ppm	†References
Mount Edith II	Om	IIIB	7·6		9·44	0·53	27	52		This work
					9·18	0·66				15
					9·40	0·53				Recommended value
Mount Egerton					6·0	0·33	38	112		This work
			7·5		6·38					17
					6·2					Recommended value
Mount Magnet	D-Opl	Anom.	7·7		14·85	0·57	6·6	8		This work
				50						6
					14·72	0·54	6·4	<1		7
					14·56		7·53	5·26	0·12	18
					13·56	0·77				19
							7·3	5·0		12
							7·7	5·3		20
							7·3			1
					14·71	0·56	7·5	5·3		Recommended value
Mount Stirling	Og-Ogg	I	7·9		6·81	0·45	93	337		This work
				3						6
					6·93	0·55	63	409		7
					6·48		48	142	6·7	8
					6·79		86·6	338	1·45	21
					6·72	0·81				15
					7·04	0·44				22
							88·6			1
					6·89	0·46	88	350	1·45	Recommended value
Mundrabilla	Om	Anom.	7·2		7·79	0·48	61	168		This work
							65·1			1
							65			Recommended value
Murchison Downs	Of	Anom.	7·3		10·0	0·48	20	60		This work
Nuleri	Om	Anom.	7·5		7·1	0·48		54		This work
					5·79	0·41				23
							17·4			1
					7·32					24
					7·2	0·48				Recommended value
Premier Downs I	Om	Anom.	7·5		7·72	0·48	55	179		This work
					7·46	0·64				15
					7·65	0·48				Recommended value
Premier Downs II	Om	Anom.	7·3		7·71	0·47	56	184		This work
					7·58	0·89				15
					7·67	0·47				Recommended value
Quairading	Og-Ogg	I	7·6		6·73	0·45	85	369		This work
					6·85					11
					6·75					Recommended value
Redfields	Anom.	Anom.	7·8		6·46	0·48	41	98		This work
							40·8			1
					6·65	0·48	40	93		25
					6·55	0·48	41	95		Recommended value
Roebourne	Om	IIIA	7·7		7·73	0·51	25	58		This work
				2·5						6
					8·04	0·56	15	49		7
					8·33	0·59				10
					7·85	0·53	19	53		Recommended value
Tieraco Creek	Of-Om	IIIB	7·7		10·33	0·54	14	28		This work
				1·5						6
					10·55	0·60	13	23		7
					10·72		16·2	28		16
					9·66	0·72				26
							16·4			1
					10·55	0·56	16	28		Recommended value
Warburton Range	D	IVB	7·9		18·14	0·85		<4		This work
					18·21	0·87				27
							0·23			1
							0·24			28
					18·20	0·86	0·24			Recommended value
Wolf Creek	Om	IIIB	7·2		9·40	0·50	27	45		This work
					8·6	0·4				29
					9·23		18·4	37·3	0·04	30
					9·20	0·48	20	38		Recommended value

Classification and major element analyses of iron meteorites—continued

Name	*Classification		Specific gravity	Cooling rate °C/10⁶yr.	Ni %	Co %	Ga ppm	Ge ppm	Ir ppm	†References
	Structure	Chemistry								
Wonyulgunna	Om	111B	7·6		8·86	0·51		43		This work
				2						6
					9·05	0·51	13	34		7
					8·26					13
							21·6			1
					8·80	0·51	20	36		Recommended value
Yarri	Om	111A	7·8		7·77	0·49	13	40		This work
					8·06	0·45				24
					7·91	0·47				Recommended value
Youanmi	Om	111A	7·6		7·78	0·50		30		This work
					8·08	0·87				13
							20·5			1
					7·80	0·50				Recommended value
Youndegin I....	Og-Ogg	1	7·85		6·46	0·55				31
							88	312		12
Youndegin III	Og-Ogg	1	7·8		6·7	0·45	87	345		This work
					7·01	0·93				15
							90·6			1
					6·8	0·45	90			Recommended value
Youndegin VIII	Og-Ogg	1			6·92	0·49	88	322		7
Youndegin	Og-Ogg	1		~2						6
					6·38		90·8	383	2·0	4
					6·94	0·46				22

* The *Structural classification* used is given by Buchwald (Wasson, 1970). The *Chemical classification* adopted is given by Wasson (1967b), Wasson and Kimberlin (1967), Wasson (1969), Wasson (1970) and Wasson and Schaudy (1971).

† *References*—

1. De Laeter (1972)
2. McCall (1968)
3. Goldstein (1969)
4. Wasson (1970)
5. Wiik & Mason (1965)
6. Goldstein & Short (1967)
7. Lovering *et al* (1957)
8. Wasson (1969)
9. Hey (1966)
10. Ward (1898)
11. McCall & De Laeter (1965)
12. Smales *et al* (1967)
13. Simpson (1938)
14. Frost (1965)
15. Simpson (1916)
16. Wasson & Kimberlin (1969)
17. McCall (1965)
18. Wasson & Schaudy (1971)
19. Simpson (1927)
20. Wasson (1967b)
21. Wasson (1971)
22. Moore *et al* (1969)
23. Simpson (1907)
24. Cleverly & Thomas (1969)
25. De Laeter *et al* (1972)
26. Hodge-Smith & White (1926)
27. McCall and Wiik (1966)
28. Schaudy *et al* (1972)
29. Taylor (1965)
30. Wasson (1967a)
31. Fletcher (1887).

are actually eight separate fragments named Youndegin as detailed by McCall and DeLaeter (1965). Analyses have only been made on Youndegin I, III and VIII. It has not been possible to identify the particular fragment on which analysis by Goldstein and Short (1967), Wasson (1970) and Moore *et al.* (1969) were carried out, and their analyses have therefore been listed under the title "Youndegin".

Two of the 37 meteorites listed are not siderites, but are the metallic pieces of stony-iron meteorites. The first of these, Dalgaranga, represents material recovered from a meteorite crater and described by McCall (1965) as a mesosiderite with octahedrite nodules. It was one of these nodules which was analysed in the present work. The second, Mount Egerton, has been described by McCall (1965) as a stony iron or possibly an enstatite achondrite usually rich in iron. Cleverly (1968) has examined further recoveries of this meteorite and classified it as an unbrecciated, metal bearing (21%), enstatite achondrite. A piece of the metal phase of Mount Egerton was examined in the present work.

One entry in the Catalogue (McCall and DeLaeter, 1965) is Dowerin, which Simpson (1938) had thought was of meteoritic origin. Only one small 0.35 gm fragment of this "meteorite" was available and when this was subjected to X ray analysis by Reed (1972) the nickel to iron ratio was found to be <0.2%. It is therefore not a meteorite and has not been listed in the Tables. Another meteorite described by Simpson (1938) as a fine octahedrite is Landor, but as only small fragments were available in the Collection it was impossible to analyse this meteorite except to confirm that it is a siderite.

The structural classification used in this work has been devised by Buchwald (Wasson 1970). This classification has equal logarithmic band width intervals, each octahedrite class corresponding to a range of a factor of 2.5 in kamacite band width. The boundaries have been chosen so that most meteorites belonging to a particular chemical group fall within a single structural class and this procedure minimises the differences between these classes and Tschermak-Prior classes. The chemical classification adopted in Table 1 is based on the nickel, gallium and germanium abundances of the meteorites, as described in the series of papers by Wasson and his associates.

The specific gravities of 32 of the siderites listed in Table 1 were measured as part of the present study. Wherever possible inclusion—free pieces of the meteorite were used for the determinations, although it was not always possible to be absolutely certain of the absence of troilite or schreibersite inclusions. The weathered outer surface of the meteorites was avoided in determining the specific gravity except for Loongana Station (iron), Murchison Downs, Nuleri and Premier Downs I and II where only the complete meteorites were available. The specific gravity of Mount Egerton has not been recorded since silicate inclusions were contained in the fragment studied, though Cleverly (1968) reports a value of 7.66.

The cooling rates of 13 of the meteorites have also been listed in Table 1. These data are based on electron microprobe measurements of diffusion gradients between gamma and alpha phases of meteoritic nickel iron (Goldstein and Short 1967; Goldstein 1969).

The remainder of Table 1 deals with the abundance data of nickel, cobalt, gallium, germanium and iridium. Only 9 iridium values are quoted, all of which were determined in J. T. Wasson's laboratory.

Table 2 lists all the available data on those minor elements found dissolved in the metallic phases and in non-metallic mineral inclusions. Also listed are a number of trace elements. Zinc and tin have been determined by the stable isotope dilution method using solid source mass spectrometry by Rosman (1972) and DeLaeter and Jeffery (1967) respectively. These data are probably accurate to ±2% of the quoted values and since at least 1 g samples were dissolved for the experiment, heterogeneity errors should also be minimal. Lovering *et al.* (1957) determined chromium and copper on a number of the samples using emission spectroscopy. Their data should be accurate to ± 5% of the quoted values. The data of Smales *et al.* (1967) on Ballinoo, Mount Edith I, Mount Magnet and Youndegin cover the widest range of trace elements analysed by any of the authors. These data were obtained by neutron activation analysis and the accuracy of the results has been discussed in their paper.

Table 2

Trace element analyses of iron meteorites (in ppm)

Name	C	P	S	Cr	Cu	Zn	As	Mo	Pd	Ag	In	Sn	Sb	†References
Avoca (Western Australia) ..						1·26								1
Ballinoo		5000												2
		4800	300		600									3
		930												4
				59	253									5
				66	233	<1	7·0	8·5	3·8	0·04	<0·01		0·17	6
Duketon		2410	300											7
Gundaring				48	156									5
Haig						2·3						0·1		1
														8
Kumerina		920												4
						0·036								1
												0·7		8
Milly Milly	200	2000	100											9
						1·96								1
												0·15		8
Mooranoppin	6700	4200												10
		690												4
				<1	175									5
Mount Dooling	100	2700	900		200									10
				28	166									5
						12								1
												0·5		8
Mount Edith I		3500												10
	200	3200	100		100									3
		950												4
				<1	147									5
				5·6	147	1·2	12·9	8·5	6·8	<0·01	0·0007		0·11	6
Mount Edith II		5000												10
Mount Magnet		500												11
		690												4
				<1	162									5
				5·3	179	<1	21·3	4·8	9·3	0·01	<0·01		0·47	6
						<0·4								1
												1·2		8
Mount Stirling	475	2000	50		145									12
	2400	1700	60											10
				7·2	225									5
						90								1
												5·3		8

Trace element analyses of iron meteorites (in ppm)—continued

Name	C	P	S	Cr	Cu	Zn	As	Mo	Pd	Ag	In	Sn	Sb	†References
Mundrabilla ..						15·5								1
Nuleri	100	1300												13
Premier Downs I	400	2100	400											10
Premier Downs II	2·47%	3100	Nil		3100									10
Redfields	0·5%		0·1%			0·94								1 8
Roebourne		1156		44	190									2 5
Tieraco Creek	80	2030	1430	<1	110	0·92								14 5 1
Warburton Range						<1 0·026					0·2			6 1 8
Wonyulgunna				1·2	118									5
Yarri		1700	40		220									15
Youanmi	500	1500	200		1100									9
Youndegin I		2400 1100	10·3	14·2	119	36	12	4·9	3·9	0·05	0·012		0·46	16 4 6
Youndegin III	1500	3000			200	42						7·6		10 1 8
Youndegin VIII				2·5	155									5
Youndegin	50	2100	300		150									12

† *References*
1. Rosman (1972)
2. Ward (1898)
3. McCall & De Laeter (1965)
4. Reed (1969).
5. Lovering *et al* (1957)
6. Smales *et al* (1967)
7. Frost (1965)
8. De Laeter & Jeffery (1967)
9. Simpson (1938)
10. Simpson (1916)
11. Simpson (1927)
12. Moore *et al* (1969)
13. Simpson (1907)
14. Hodge-Smith & White (1926)
15. Cleverly & Thomas (1969)
16. Fletcher (1887).

It is uncertain with what confidence one can quote the pre-1940 analyses of Ward (1898), Simpson (1907, 1916, 1927, 1938), Hodge-Smith and White (1926) and Fletcher (1887). Many of the data given by McCall and DeLaeter (1965) are also pre-1940 analyses performed by a number of analysts, many of whom were employed by the Western Australian Government Chemical Laboratories.

Reed (1969) has analysed a number of the siderites listed in Table 2 for phosphorus, but it should be noted that the analyses refer to the kamacite phase only, and not to the meteorite as a whole. Because of the paucity of analytical information on these minor and trace elements, no recommended values have been given.

Iron was not determined in this study. It is very difficult to determine a constituent making up approximately 90% of a sample with sufficient precision to be comparable with the other measurements. In order to determine an unmeasured component the iron value would have to be precise to four significant figures. Many of the analyses in the literature list iron values, but these were usually determined by difference, and are therefore of doubtful value and have not been included in the tables.

Nichiporuk and Chodos (1959) have analysed the troilite phase of 12 meteorites for 8 elements, but the only Western Australian siderite in the group is Ballinoo. They list the following data for this meteorite: iron 78.5%, nickel 4.82%, cobalt 0.30%, vanadium <13 ppm, chromium 0.12 ppm, copper 771 ppm, zinc <50 ppm and arsenic <50 ppm. The analytical method used was X-ray fluorescence, and the authors have estimated their accuracy limits for each of the elements analysed.

Conclusions

Since the publication of the Catalogue of Western Australian Meteorite Collections in 1965, a large and significant body of analytical data has been published by a variety of authors both in Western Australia and overseas. It is now recognised that the structural classification of iron meteorites depends on the kamacite bandwidth and can not be made simply in terms of the nickel content of the meteorite involved. Many of the older designations have therefore been altered in terms of Buchwald's classifications.

The importance of the gallium-germanium groups has now been recognised as a means of classifying iron meteorites on a chemical basis, and the groups have been used to infer genetic and environmental relationships between various meteorites. The theory of cooling rate determinations from nickel diffusion profiles has been developed in the last decade and this has enabled the thermal history of meteorites to be investigated with important conclusions as to the size of the meteorite parent bodies.

Another development in recent years has been the use of physical methods of analysis in determining the abundance of elements in a wide variety of materials. Data from neutron activation analysis, X-ray fluorescence spectrometry, stable isotope dilution (using solid source mass spectrometry) and electron microprobe analysis have all been reported in this paper. Prior to 1965, traditional wet chemical analyses and emission spectroscopy were the only methods used in the abundance data included in the Catalogue. Many of the Western Australian meteorites had never been analysed for more than one or two elements, and some of the older data were suspect. The present project has included the analysis of every iron meteorite found in Western Australia for nickel, cobalt, gallium and germanium, including those meteorites discovered since 1965.

One important outcome of the study has been to provide additional information on paired falls. A number of the Western Australian meteorites are believed to be fragments of the same fall masquerading under different names. The most famous case is that of the Youndegin shower. A diagram reproduced by McCall and DeLaeter (1965, page 57) shows the approximate locations of Youndegin I-VIII, Mooranoppin, Mount Stirling and Quairading. This group of 11 meteorites has a restricted geographical distribution, and on the evidence presented in this paper, are members of the same fall. It is hoped to procure additional samples of these meteorites so that a full investigation of all 11 meteorites may be carried out.

Another group of meteorites which are thought to be part of the same fall are Loongana Station (iron) and the Premier Downs meteorites, (McCall and DeLaeter 1965). To these can now be added Mundrabilla, a large iron meteorite tentatively described as being connected to the other meteorites by McCall and Cleverly (1970). All these meteorites come from a restricted locality along the Trans-Australian Railway on the Nullarbor Plain. The chemical evidence presented in this paper supports the concept that these are members of the same meteorite shower.

It is equally important to know which meteorites thought to be paired are, in fact, from separate falls. Mount Edith I and II were found in 1913 and 1914 respectively at locations some 3.2 km apart. They were therefore identified as belonging to the one fall, and the chemical evidence presented in this paper supports this contention.

The data presented in this paper have reinforced the necessity for some type of interlaboratory comparisons to be made by those involved in meteorite analyses. It is now customary for laboratories making silicate rock analyses to use the set of standard rocks provided by the United States Geological Survey. The National Bureau of Standards has also been active in producing a variety of standard metal alloys. However no existing metal standards serve the requirements for siderite analyses. It is to be hoped that pieces of a large iron meteorite, which have been tested for homegeneity and absence of significant mineral inclusions, might be distributed among laboratories involved in meteorite research, so that future analyses of iron meteorites might be made with more stringent confidence limits than has been possible in the past.

Acknowledgments.—The author is indebted to Mr. W. W. Thomas for assisting with the X-ray analyses. Most of the meteorite samples were generously supplied by the Western Australian Museum Board to whom appreciation is expressed. The author would also like to thank Dr. G. J. H. McCall, Mr. W. H. Cleverly and Dr. C. Pearson for assisting in many ways.

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